Chapter 2. Oceanographic Conditions

Introduction

The City of San Diego collects a comprehensive suite of oceanographic data from offshore ocean waters surrounding both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) to characterize conditions in the region and to identify possible impacts of wastewater discharge. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen (DO), pH, chlorophyll *a*, and colored dissolved organic matter (CDOM) are important indicators of physical and biological oceanographic processes (e.g., Skirrow 1975, Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an ocean outfall's diffuser structure and rate of discharge, but also by oceanographic factors that govern water mass movement (e.g., water column mixing, ocean currents), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping. Further, previous studies have shown that wastewater plumes can often be identified by having lower salinity and higher CDOM values than background conditions (Terrill et al. 2009, Todd et al. 2009).

In nearshore coastal waters of the Southern California Bight (SCB) such as the Point Loma outfall region, oceanographic conditions are strongly influenced by several factors, including (1) global and regional climate processes such as El Niño/La Niña, Pacific Decadal and North Pacific Gyre oscillations that can affect long-term (~10–20 years) trends (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, 2011, NOAA/NWS 2011), (2) the California Current System coupled with local gyres that transport distinct water masses throughout the SCB (Lynn and Simpson 1987), and (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). The seasonality of southern California is responsible for the main stratification patterns of the coastal waters off San Diego. Warmer waters and a more stratified water column are typically present during the dry season (April–September), while cooler waters and weak stratification characterize ocean conditions during the wet season (October–March) (Terrill et al. 2009). For example, storm activity during the winter brings higher winds, rain, and waves that often contribute to the formation of a well-mixed, non-stratified water column (Jackson 1986). The chance of wastewater plumes from sources such as the PLOO reaching surface waters is highest during these times since no barriers (temperature, salinity gradients) exist. These winter conditions often extend into spring until the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the surface waters begin to warm, which results in increased surface evaporation (Jackson 1986). Once the water column becomes stratified, minimal mixing conditions typically remain throughout the summer and early fall months. In the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

Understanding changes in oceanographic conditions due to natural processes such as seasonal patterns and shifting current regimes is important since they can affect the transport and distribution of wastewater, storm water and other types of turbidity (e.g., sediment) plumes. In the Point Loma outfall region such processes include outflows from local bays, major rivers, lagoons and estuaries, discharges from storm drains or other point sources, surface runoff from local watersheds, seasonal upwelling, and changing ocean currents or eddies. For example, flows from San Diego River, San Diego Bay and the Tijuana River are fed by 1140 km^2, 1165 km^2 and 4483 km^2 of watersheds, respectively (Project Clean Water 2012), and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009, Svejkovsky 2010).

This chapter presents analyses and interpretations of the oceanographic data collected during 2011 at fixed monitoring stations surrounding the PLOO. The primary goals are to: (1) summarize oceanographic conditions in the region, (2) identify potential natural and anthropogenic sources of variability, (3) assess possible influence of the PLOO wastewater plume relative to other inputs, and (4) determine the extent to which water mass movement or water column mixing affects the dispersion/dilution potential for discharged materials. Results of remote sensing observations (e.g., satellite imagery) are combined with measurements of physical oceanographic parameters to provide additional insight on the horizontal transport of surface waters in the region (Pickard and Emery 1990, Svejkovsky 2012). In addition, a multi-phase project is currently underway to examine the dynamics and strength of the thermocline and ocean currents off Point Loma, as well as the dispersion behavior of the PLOO wastewater plume using a combination of current meters, thermistor strings, and automated underwater vehicles (see Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010, Rogowski et al. in press). Finally, the results reported in this chapter are also referred to in subsequent chapters to help explain patterns of indicator bacteria distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

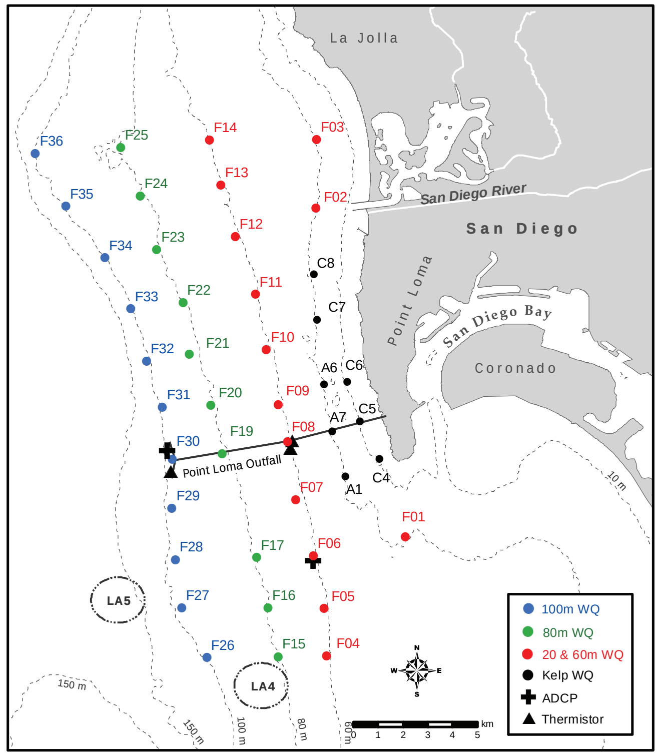

Figure 2.1
Locations of moored instruments (i.e., ADCP, thermistor) and water quality (WQ) monitoring stations where CTD casts are taken around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Materials and Methods

Field Sampling

Oceanographic measurements were collected at 44 fixed sampling sites arranged in a grid pattern surrounding the PLOO and encompassing an area of ~146 km^2 (Figure 2.1). These include 36 offshore stations (designated F01–F36) located between ~1.7 and 10.2 km offshore of Point Loma along or adjacent to the 18, 60, 80, and 100-m depth contours, and eight kelp bed stations (A1, A6, A7, C4–C8) distributed along the inner (9 m) and outer (18 m) edges of the Point Loma kelp forest. Monitoring at the offshore stations occurs quarterly (February, May, August, November) to correspond with similar sampling for the Central Bight Regional Water Quality Monitoring Program conducted off Orange County, Los Angeles County, and Ventura County. For sampling and analysis purposes, the quarterly water quality monitoring sites are grouped by depth contour as follows: (a) "100-m WQ" = stations F26–F36 (n = 11); (b) "80-m WQ" = stations F15–F25 (n = 11); (c) "20 & 60-m WQ" = stations F01–F14 (n = 14). All stations within each of these three groups are sampled on a single day during each quarterly survey. In addition, sampling at the eight kelp bed stations ("Kelp WQ") is conducted five

Table 2.1

Sample dates for quarterly oceanographic surveys conducted in the Point Loma outfall region during 2011. Each survey was conducted over four consecutive days with all stations in each station group sampled on a single day (see Figure 2.1 for stations and locations).

	2011 Quarterly Survey Dates			
Station Group	Feb	May	Aug	Nov
20 & 60 m WQ	8	4	16	1
80 m WQ	9	5	17	2
100 m WQ	10	6	18	3
Kelp WQ	11	7	19	4

times per month to meet monitoring requirements for fecal indicator bacteria; however, only Kelp WQ data collected within 1 day of the quarterly stations are analyzed in this chapter, such that all stations were sampled over a 4-day period (see Table 2.1).

Oceanographic data were collected using a SeaBird conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), DO, and CDOM. Water column profiles of each parameter were then constructed for each station by averaging the data values recorded in each 1-m depth interval. This data reduction ensured that physical measurements used in subsequent analyses corresponded to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Moored Instrument Data Collection

Moored instruments, including current meters (ADCPs: Acoustic Doppler Current Profilers) and vertical arrays of temperature sensors (thermistors) were deployed at three primary locations off Point Loma in order to provide nearly continuous measurements of ocean currents and water temperatures for the area. These included one site near the present PLOO discharge zone at a depth of about 100 m, one site located near the outfall pipe at a depth of about 60 m, and one site located south of the outfall along the 60-m depth contour (Figure 2.1).

Ocean current data were collected throughout 2011 using one ADCP moored at two of the above sites (i.e., 100-m site, 60-m site south of the outfall). The ADCP data were collected every five minutes and then averaged into depth bins of 4 m. For the 60-m ADCP, this resulted in 15 bins that ranged in depth from 5 to 53 m; data from this ADCP were unavailable from July 16 through August 3 and from October 19 through December 22 due to battery failure. For the 100-m ADCP, 25 bins were created that ranged in depth from 5 to 93 m. Data from the 100-m ADCP were unavailable from April 22 through August 11 due to a failed deployment. Additional details for processing and analyzing the ADCP data are presented below under 'Data Analysis.'

Temperature data were collected every 10 minutes throughout 2011 from thermistor strings located at the 100-m and 60-m outfall mooring sites. The individual thermistors (Onset Tidbit temperature loggers) were deployed on mooring lines at each site starting at 2 m off the seafloor and extending in series every 4 m to within 6 m of the surface. Occasional gaps exist in the time series where individual thermistors were lost at sea or failed to record data properly. Additional details on specific methodology are available in Storms et al. (2006).

Remote Sensing

Coastal monitoring of the PLOO region during 2011 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite imaging data acquired during the year were made available for review and download from OI's website (Ocean Imaging 2012), while a separate annual report summarizing results for the year was also produced (Svejkovsky 2012). Several different types of satellite imagery were analyzed, including Moderate Resolution Imaging Spectroradiometer (MODIS), Thematic

Mapper TM7 color/thermal, and high resolution Rapid Eye images. These technologies differ in terms of their capabilities as described in the "Technology Overview" section of Svejkovsky (2012), but are generally useful for revealing patterns in surface waters as deep as 12 m, depending on ocean conditions (e.g., water clarity).

Data Analysis

With the exception of CDOM, the various water column parameters measured in 2011 were summarized as means of surface (top 2 m) and bottom (bottom 2 m) waters for each survey pooled over all stations along each of the 9, 18, 60, 80, and 100-m depth contours. CDOM data were not included in these summaries due to calibration issues with individual CDOM probes that made absolute (measured) values unreliable. For spatial analysis, 3-D graphical views were created for each survey using Interactive Geographical Ocean Data System (IGODS) software, which interpolates data across all depths at each site and between stations along each depth contour. CDOM data were included as part of the IGODS analyses using relative values that were not affected by the calibration issues mentioned above. Additionally, a time series of anomalies for each parameter was created to evaluate significant oceanographic events that have occurred in the region. The anomalies were calculated by subtracting the mean of all 21 survey years to date combined (i.e., 1991–2011) from the monthly means for each year. These mean values were calculated using data from all 100-m depth contour stations, with all water column depths combined.

Because ocean currents typically vary by season, the ADCP data were subset into four seasons prior to conducting subsequent analyses: (a) Winter (December–February); (b) Spring (March–May); Summer (June–August); and Fall (September–November). Although the winter period for 2011 includes non-continuous months (i.e., January–February versus December), preliminary analysis suggested that the current regimes for these three months were similar enough to justify pooling them together for analysis. Since tidal currents are predictable and not likely to result in a net flow of water in a particular direction, tides were filtered prior to any data visualization or analysis using the PL33 filter developed by C. Flagg and R. Beardsley (Alessi et al. 1984). In order to examine modes of currents that were present each season, an empirical orthogonal function (EOF) analysis was completed by singular value decomposition (Anderson et al. 1999) in MATLAB (2012). The first EOF mode for currents was plotted on compass plots for selected depth bins.

Results and Discussion

Oceanographic Conditions in 2011

Water Temperature

Average surface temperatures in 2011 ranged from 14°C in February to 19.6°C in August across the PLOO based on CTD data collected from all of the quarterly water quality stations, while bottom temperatures averaged from 9.7°C in February to 15.7°C in August (Appendix A.1). Although these data were limited to only four surveys, ocean temperatures varied by season as expected, with no discernible patterns relative to wastewater discharge (Figure 2.2). For example, the lowest average temperatures of the year occurred during May at bottom depths, which was likely indicative of spring upwelling. However, relatively cold water (<~11ºC) was also present near the bottom at most of the 60, 80 and 98-m stations during all four surveys, which suggests that upwelling may have occurred at other times as well. Thermal stratification also followed expected seasonal patterns, with the greatest difference between surface and bottom water temperatures (~10°C) occurring during late summer (August). Temperature data from the 60 and 100-m thermistor strings yielded similar results, thus indicating that the general thermal stratification patterns observed during the quarterly CTD surveys actually persisted throughout much of the year (Figure 2.3).

Salinity

Average salinities for the PLOO region in 2011 ranged from 33.30 psu in November to 33.57 psu

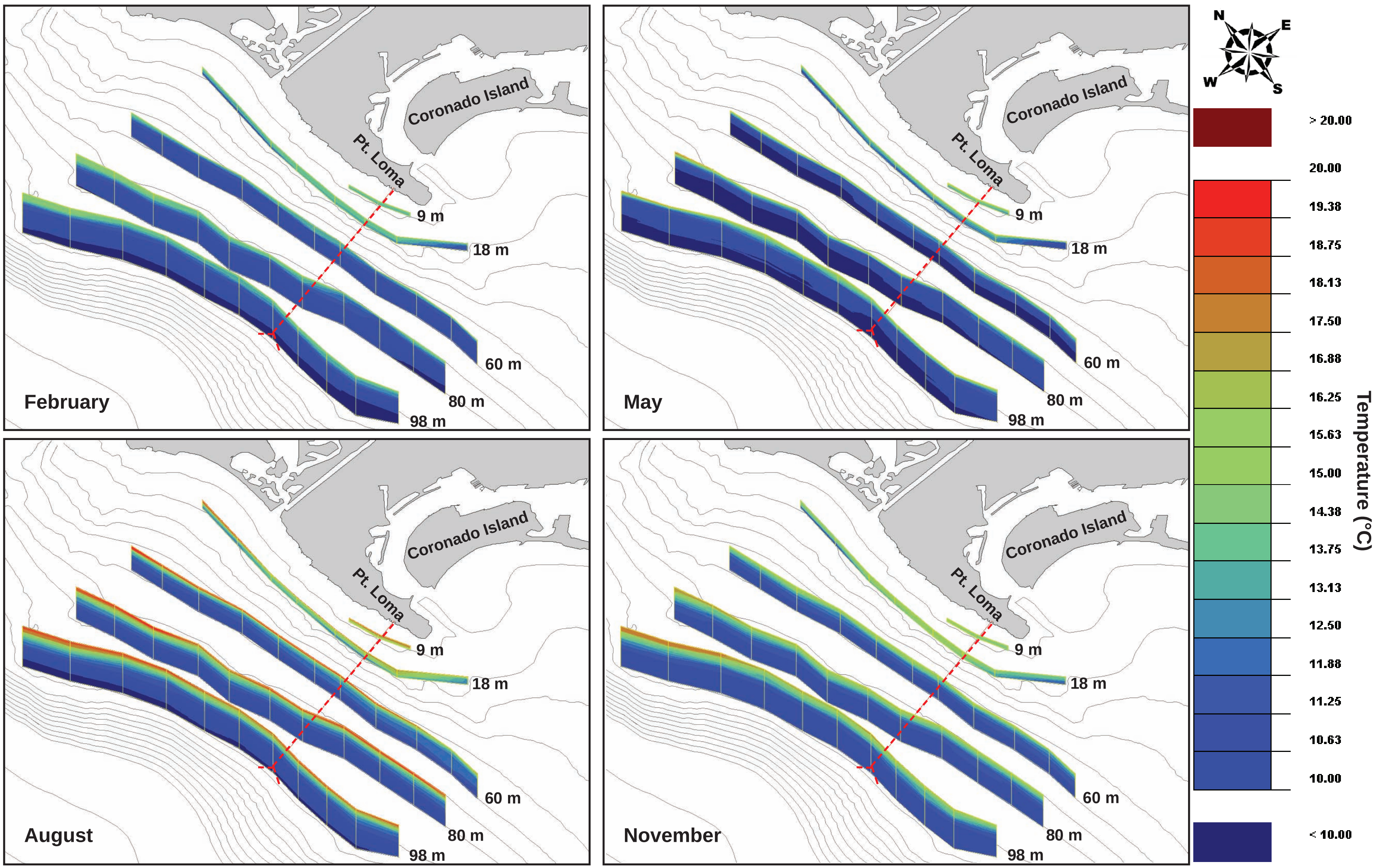

Figure 2.2

Ocean temperatures recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.

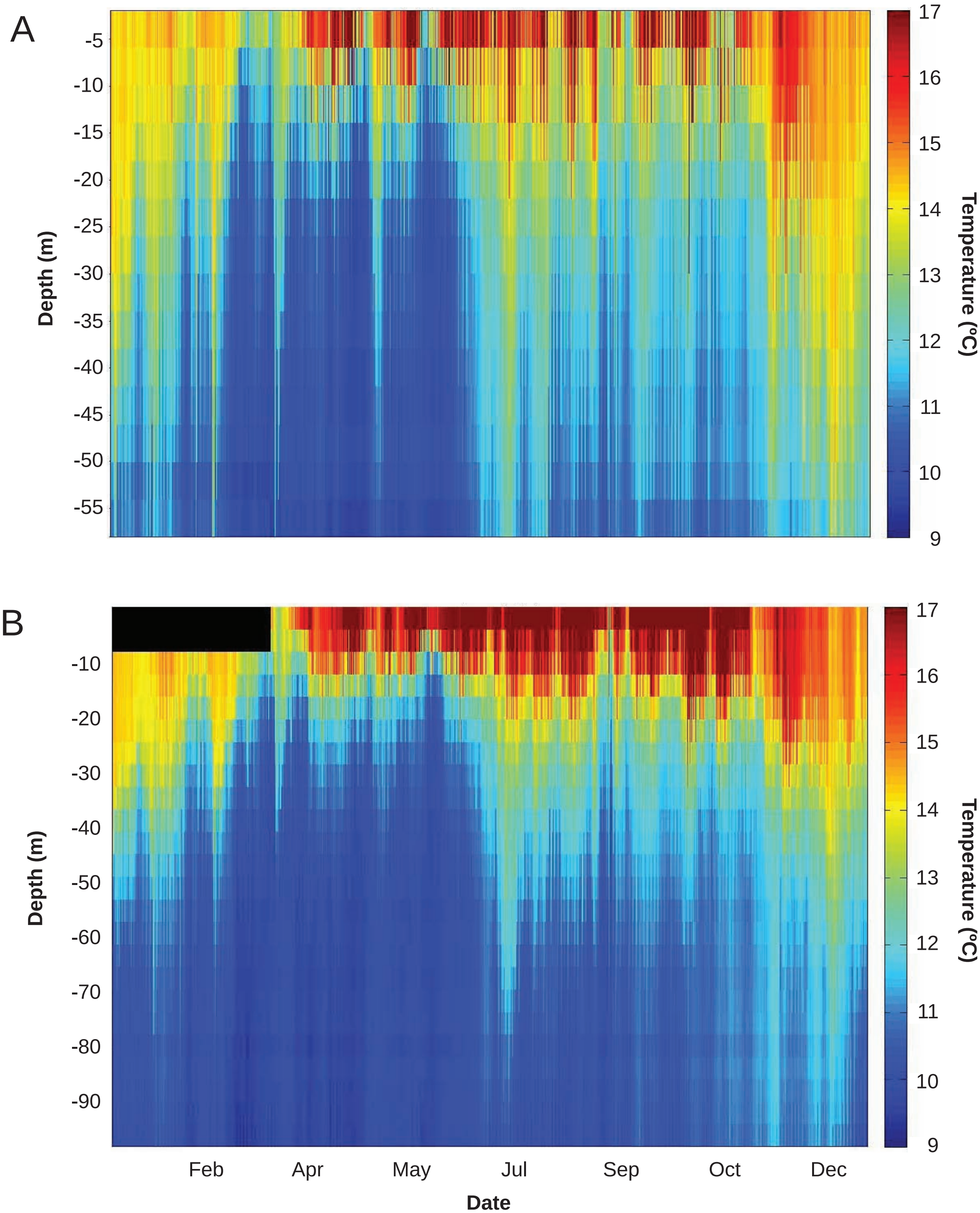

Figure 2.3
Temperature logger data collected at the (A) 60-m and (B) 100-m thermistor sites between January and December 2011. Data were collected every 10 minutes. Missing data (black area) are the result of individual thermistors that were lost at sea.

in May for surface waters, and from 33.32 psu in November to 33.95 psu in May at bottom depths (Appendix A.1). As with ocean temperatures, salinity appeared to vary by season, with no discernible patterns relative to wastewater discharge (Figure 2.4). Relatively high salinity (>~33.6 psu) was present at bottom depths of most 60, 80, and 98-m stations during all four surveys, with the highest values occurring at bottom depths during May. Higher salinity values tended to correspond with lower temperatures found at bottom depths as described above. Taken together, these factors are likely indicative of local coastal upwelling (Jackson 1986).

As in previous years, there was some evidence of another region-wide phenomenon that occurred during May and August, when a layer of relatively low salinity values occurred at mid-water or "sub-surface" depths between about 10–40 m. It seems unlikely that this sub-surface salinity layer (SSL) could be due to wastewater discharge from the PLOO for two reasons. First, seawater samples collected at the same depths and times did not contain levels of indicator bacteria (see Chapter 3). Second, similar SSLs have been reported previously off San Diego and elsewhere in southern California, including Orange and Ventura Counties (e.g., OCSD 1999, 2009, City of San Diego 2011a, b, 2012). Further investigations are required to determine the possible source(s) of this phenomenon.

Dissolved Oxygen and pH

DO concentrations averaged from 7.6 mg/L in August to 10.9 mg/L in May in surface waters, and from 2.7 mg/L in November to 9.7 mg/L in May in bottom waters across the Point Loma outfall region in 2011. Mean pH values ranged from 8.1 in February and November to 8.3 in May in surface waters, and from 7.6 in November to 8.2 in May in bottom waters (Appendix A.1). Changes in pH were closely linked to DO concentrations (e.g., Appendices A.2, A.3) since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). Similar distributions of both pH and DO values across all stations and along each depth contour indicate that the quarterly surveys were synoptic even though sampling occurred over a 4-day period (Table 2.1, Appendices A.2, A.3).

DO and pH stratification followed normal seasonal patterns, with maximum stratification occurring during the spring (i.e., May) (Appendices A.1, A.2, A.3). Low DO concentrations and pH values at mid- and deeper depths during each survey may have been due to cold, saline and oxygen poor waters moving inshore during periods of local upwelling as described above for temperature and salinity. In contrast, very high DO values just below surface waters were likely associated with phytoplankton blooms that were evident by high chlorophyll values at the same depths and surveys (see below). Changes in DO and pH levels relative to wastewater discharge were not discernible during the year.

Transmissivity

Water clarity varied within typical ranges for the PLOO region during 2011, with average transmissivity values between 70–89% in surface and bottom waters (Appendix A.1). Transmissivity was consistently higher at the offshore sites than in inshore waters, by as much as 18% at the surface and 15% near the bottom. Reduced transmissivity at surface and mid-water depths appeared to co-occur somewhat with peaks in chlorophyll concentrations associated with phytoplankton blooms (Appendices A.4, A.5). Lower transmissivity during February and November may also have been due to wave and storm activity and resultant increases in suspended sediment concentrations. For example, substantial turbidity plumes were evident throughout the region in a satellite image taken February 10, 2011 following a major rain event (Figure 2.5). This plume was massive enough to extend past the end of the PLOO, and corresponded to lower water clarity that reached as far offshore as the 98-m stations at surface depths (Appendix A.4). In contrast, reductions in transmissivity that occurred offshore at depths >60 m were more likely associated with wastewater discharge from the PLOO. During 2011, reduced water clarity was most evident in August at station F30 located nearest the discharge site. This observation was corroborated by relatively

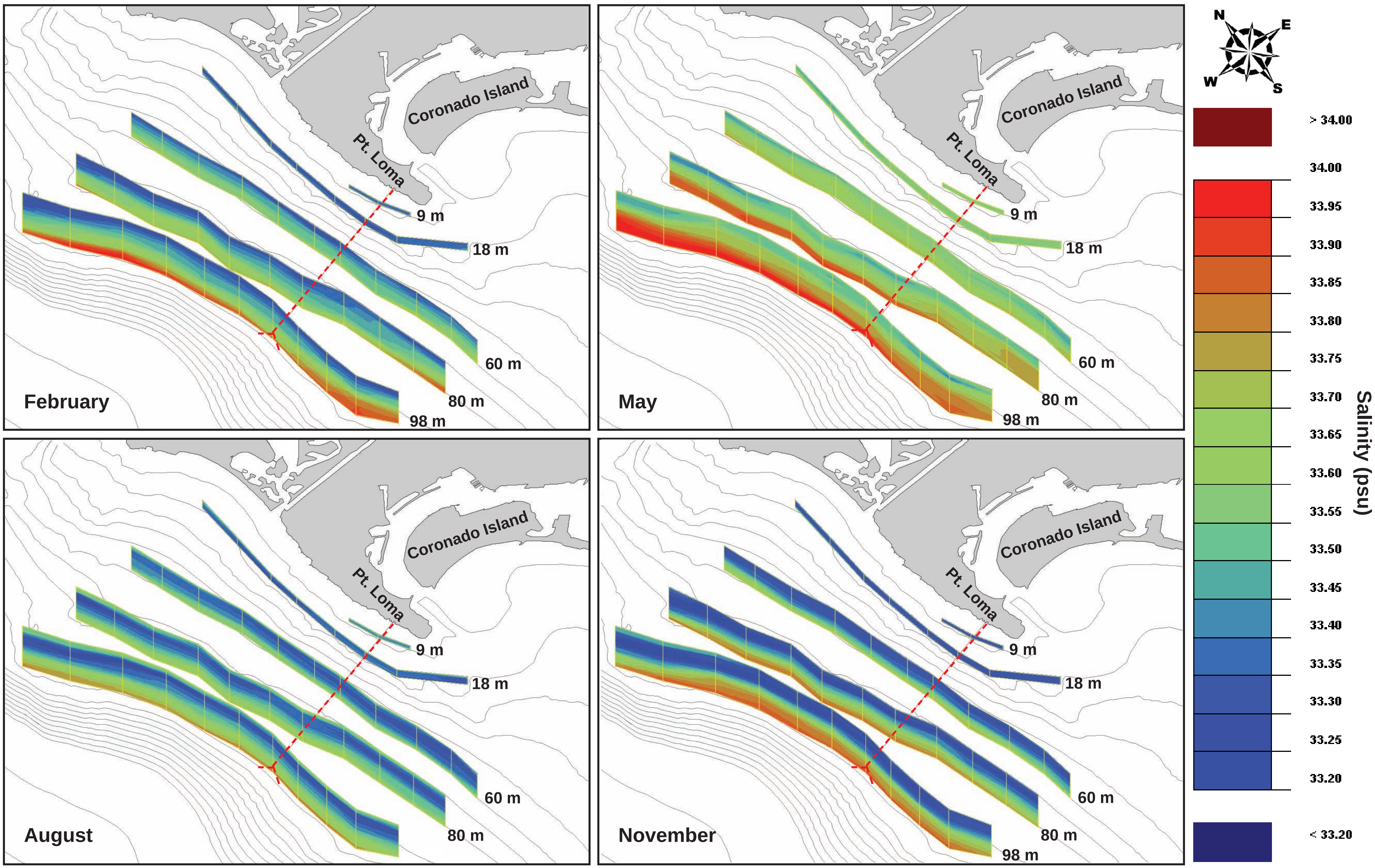

Figure 2.4
Levels of salinity recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.

Figure 2.5
Rapid Eye satellite image of the Point Loma region acquired February 10, 2011 (Ocean Imaging 2012) showing extensive turbidity plumes originating from Mission Bay, San Diego Bay, and other coastal sources.

high CDOM values at this location during the same survey (e.g., Figure 2.6). However, relatively high CDOM values were also found at station F30 at depths below 60 m during February, May and November as well. These results also corresponded somewhat to occasional elevated enterococcus counts over the past year.

Chlorophyll a

Chlorophyll concentrations averaged from 1.5 mg/L in August to 17.4 mg/L in November in surface waters, and from 0.4 mg/L in February and November to 23.5 mg/L in November in bottom waters (Appendix A.1). However, subsequent analysis clearly showed that the highest chlorophyll concentrations typically occurred at sub-surface depths during all quarters (Appendix A.5), reflecting the fact that phytoplankton often mass at the bottom of the pycnocline (Lalli and Parsons 1993). For example, the highest concentrations of chlorophyll *a* in 2011 were observed 10 to 20 m below the surface during May across much of the region. Remote sensing observations revealed that the Point Loma outfall region was consistently influenced by phytoplankton blooms between early March and October (Svejkovsky 2012). These data showed that the frequency of blooms was considerably higher during 2011 than in most previous years, and that the blooms often extended seaward beyond the end of the PLOO (e.g., Figure 2.7). Samples from the red tide blooms depicted in Figure 2.7 were dominated by the dinoflagellate *Lingulodinium polyedrum*.

Summary of Oceanographic Currents in 2011

In the ocean current data analysis summarized below, the first EOFs for all seasons at the 100-m ADCP site indicated the primary current direction was in the north-south axis for all depth bins, with some deviations slightly northwest-southeast (for example the 11-m depth bin during summer) or slight deviations northeast-southwest (for example, the 11-m depth bin during winter) (Figure 2.8). Overall, currents were strongest in the 11-m depth bin. The strongest of all currents occurred in spring. Trends in direction and magnitude seen in the first EOF were generally the same in the second EOF, with lower magnitude currents overall in the 35-m depth bin and higher magnitude currents in the 63 and 91-m depth bins than in the first EOF. Mean current speeds at the end of the PLOO during quarterly sampling events were very slow, all less than 0.125 m/s.

The first EOF modes for the 60-m currents were slightly different than those at the 100-m ADCP station (Figure 2.9). Most current directions during all seasons were along the northeast-southwest axis. However, during fall the first EOF at all depth bins was oriented along the north-south axis. As in the 100-m ADCP data, the strongest currents were in the 11-m depth bin. However the strongest currents at the 60-m ADCP were recorded in the fall.

Historical Assessment of Oceanographic Conditions

A review of 21 years (1991–2011) of oceanographic data collected at stations along the 98-m depth contour revealed no measurable impacts that could

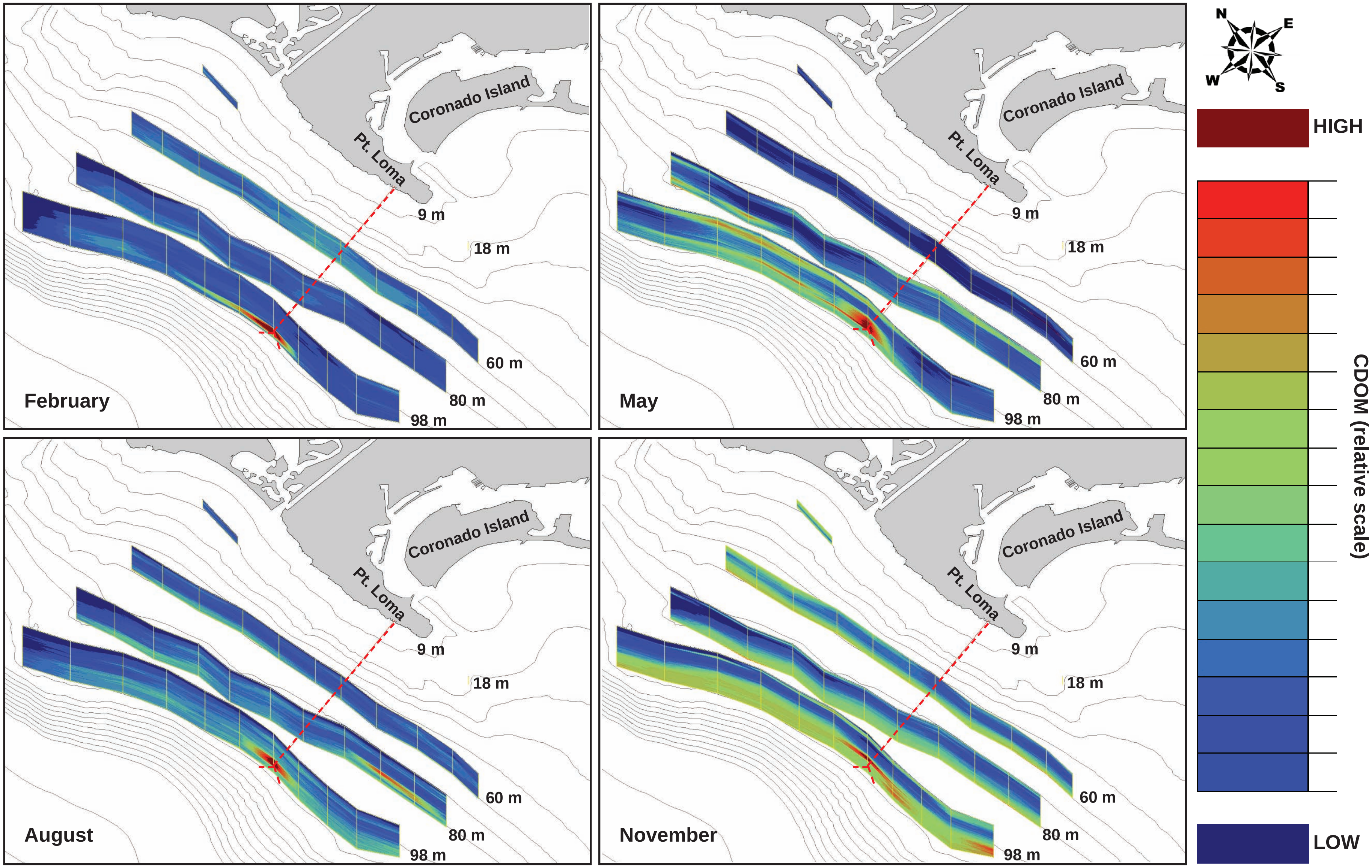

Figure 2.6
Relative CDOM values recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day. For each sampling event, the highest value was set to red and the lowest was set to blue.

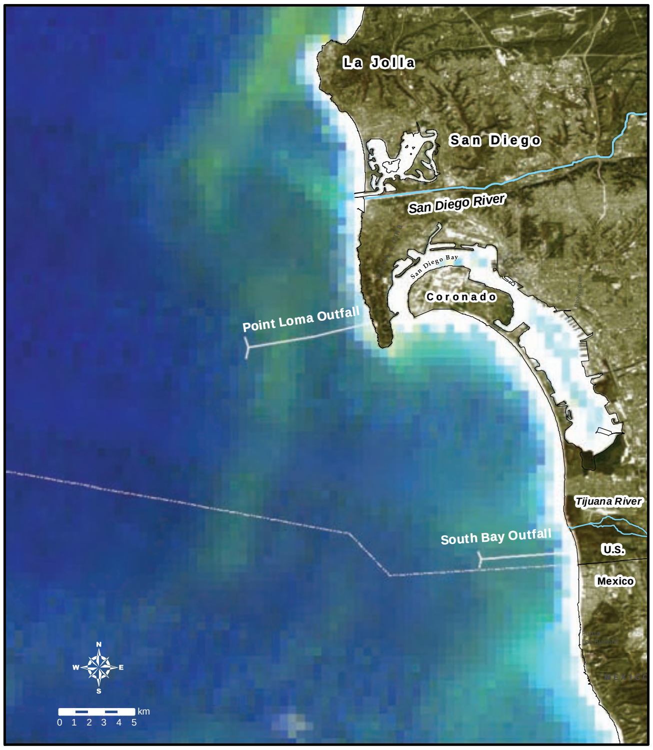

Figure 2.7
Wide-spread phytoplankton blooms in San Diego's nearshore waters acquired on September 8, 2011 with Terra MODIS imagery (from Ocean Imaging 2012).

be attributed to wastewater discharge (Figure 2.10). Although the change from monthly to quarterly sampling in late 2003 reduced the number of data points for interpretation, results are still consistent with described changes in large-scale patterns in the California Current System (CCS) as described in Peterson et al. (2006), McClatchie et al. (2008, 2009), Bjokstedt et al. (2010), and NOAA/NWS (2011). For example six major events have affected the CCS during the last decade: (1) the 1997–1998 El Niño event; (2) a shift to cold ocean conditions between 1999–2002; (3) a subtle but persistent return to warm ocean conditions beginning in October 2002 that lasted through 2006; (4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña event in 2007 that coincided with a cooling of the PDO; (6) development of a second La Niña event starting in May 2010. Ocean temperatures and salinity for the Point Loma outfall region are consistent with all but the third of these CCS events; while the CCS was experiencing a warming trend that lasted through 2006, the PLOO region experienced cooler than normal conditions during 2005 and 2006. During these two years ocean conditions off San Diego were more consistent with observations from northern Baja California (Mexico) where temperatures were well below the decadal mean (Peterson et al. 2006). During 2008 and 2009, temperatures remained cool, but closer to the overall average, whereas 2010 saw the return of cold La Niña conditions which remained through the end of 2011.

Water clarity (transmissivity) around the PLOO has tended to be higher than the historical average since about mid-1996 (Figure 2.10). This may be due in part to relatively low values recorded in 1995 and early 1996, perhaps related to factors such as sediment plumes associated with offshore disposal of dredged materials from a large dredging project in San Diego Bay. Particularly low transmissivity occurred in January of 1995 which corresponded with heavy rainfall. Subsequent reductions in transmissivity during some winters (e.g., 1998 and 2000) appear to be the result of increased amounts of suspended solids associated with strong storm activity (e.g., NOAA/NWS 2011). Additionally, there have been no apparent large-scale historical trends in DO concentrations or pH values related to the PLOO discharge.

Summary and Conclusions

Oceanographic data collected in the Point Loma outfall region concur with reports that describe 2011 as a La Niña year characterized by the early onset of relatively strong upwelling (Bjorkstedt et al. 2011). For example, colder-than-normal sea surface temperatures were observed during summer months as would be expected during La Niña conditions; these results were evident in data collected by the City and corroborated by remote sensing observations (Svejkovsky 2012). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH levels at mid-depths and below, were observed during all surveys, but were most evident during May. Phytoplankton blooms, indicated by high chlorophyll concentrations and confirmed by satellite imagery were present throughout the region during much of the year.

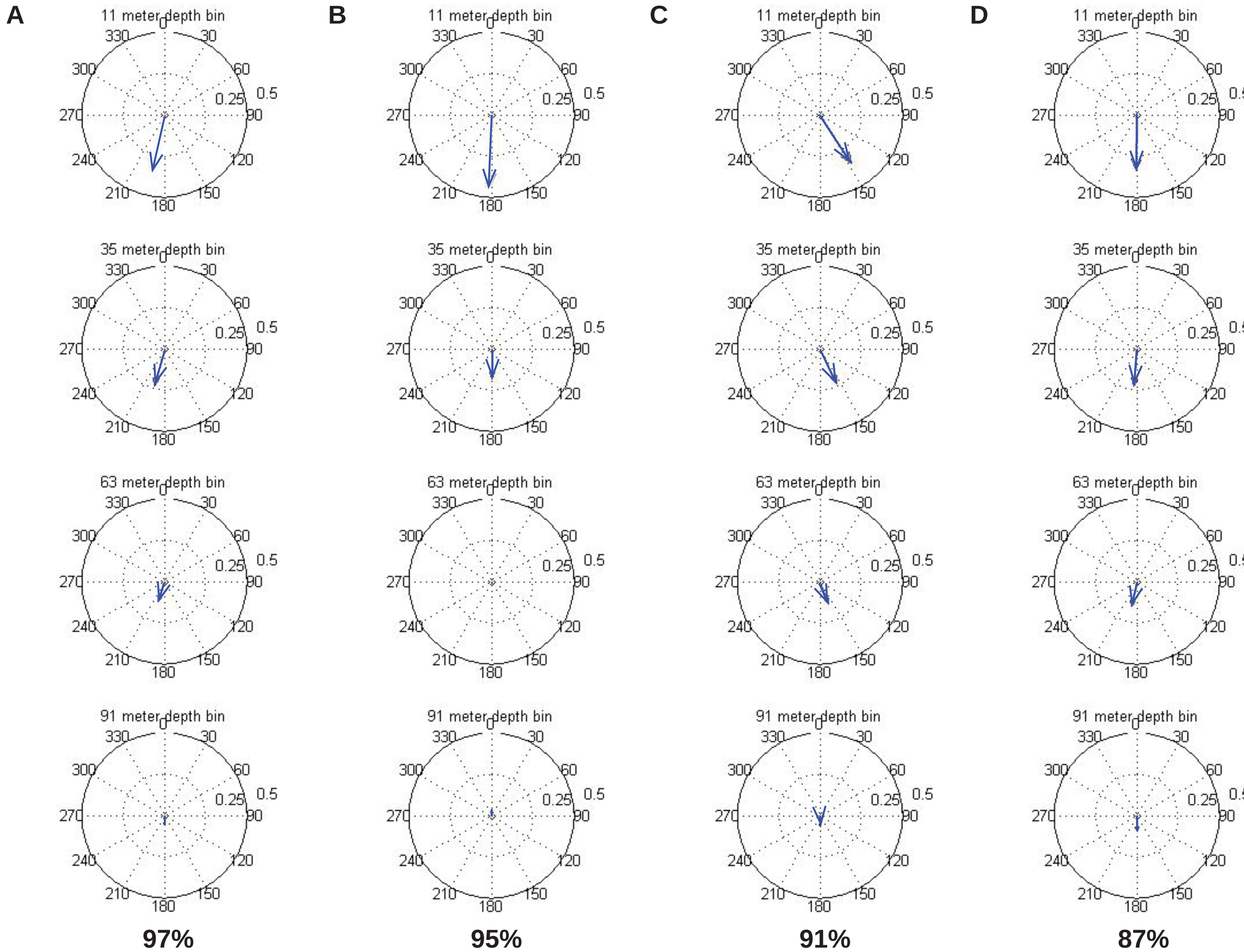

Figure 2.8
Empirical Orthogonal Function 1 (EOF) for (A) winter, (B) spring, (C) summer, and (D) fall in 2011 at the 100-m ADCP. Percentages indicate fraction of the total variance accounted for by the EOF. Arrow length indicates current magnitude in m/s.

Additionally, water column stratification followed patterns typical for San Diego coastal waters, with maximum stratification occurring in mid-summer. Further, oceanographic conditions for the region remained consistent with other well documented large-scale patterns (e.g., Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, NOAA/NWS 2011). These observations suggest that other factors such as upwelling of deep ocean waters and large-scale climatic events such as El Niño and La Niña continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

Satellite imagery results revealed no evidence of the wastewater plume reaching near-surface waters during 2011, even during the winter and fall months when the water column was only weakly stratified (Svejkovsky 2012). This is consistent with bacteriological sampling results for the same region described herein (see Chapter 3) and results of historical analyses of remote sensing observations made between 2003 and 2009 (Svejkovsky 2010). These findings have been supported by additional satellite imagery in subsequent years (Svejkovsky 2011, 2012), and by the application of IGODS analytical techniques to data collected over the past several years (City of San Diego 2010, 2011a). For example, although small differences in water clarity have been observed at the station closest to the outfall discharge site, and relatively high CDOM concentrations were found near the outfall during all surveys this year, it was clear from

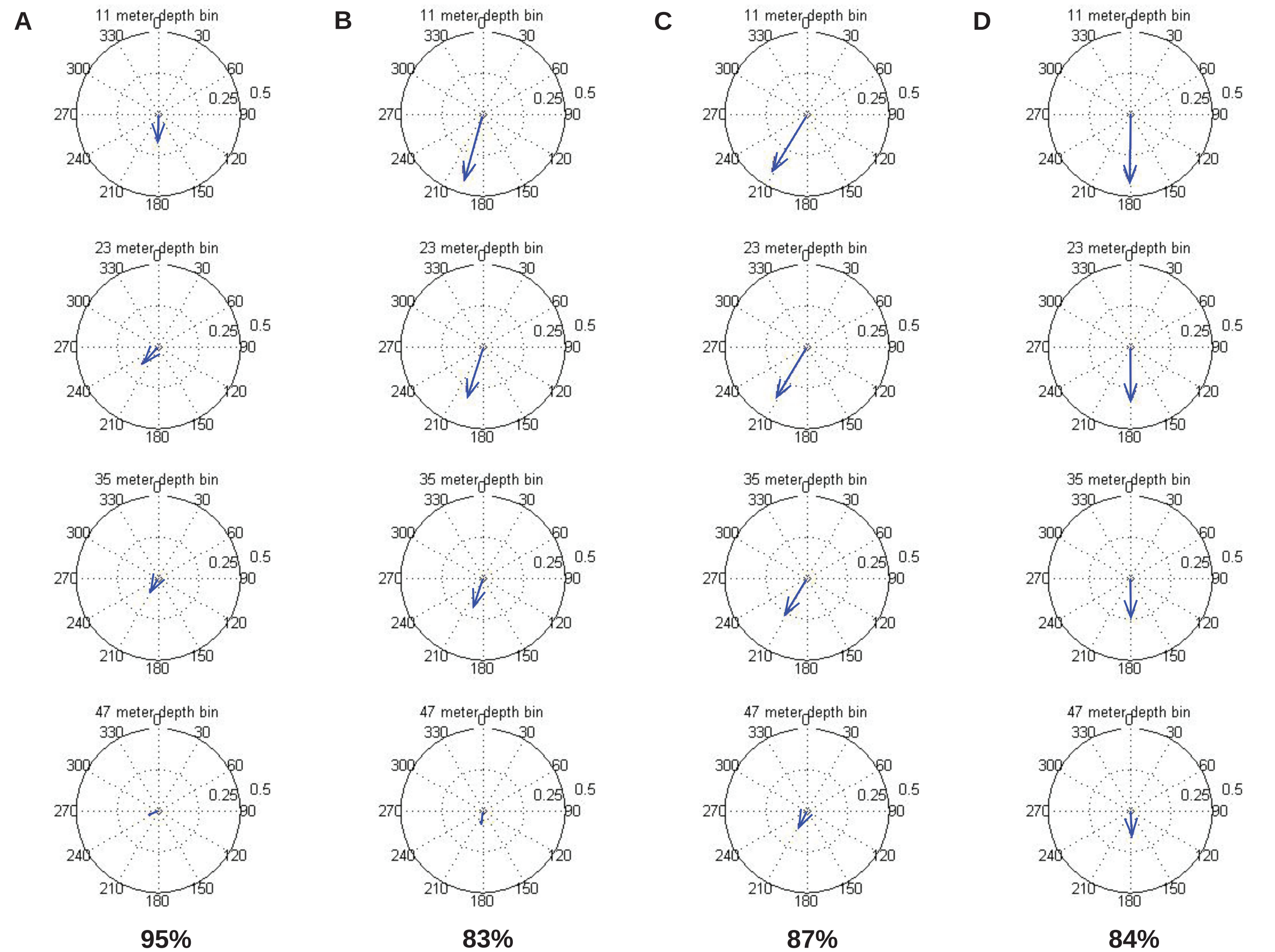

Figure 2.9
Empirical Orthogonal Function 1 (EOF) for (A) winter (B) spring (C) summer and (D) fall in 2011 at the 60-m ADCP. Percentages indicate fraction of the total variance accounted for by the EOF. Arrow length indicates current magnitude in m/s.

all analyses that variations among stations at any particular depth were very slight and highly localized. Current meter data generated in 2011 also suggested that local currents flowed in northerly and southerly directions throughout most of the year, although these measurements excluded the possible effects of tidal currents and internal waves. However, these results still suggest that current conditions off Point Loma are probably not conducive to shoreward transport of the PLOO wastefield.

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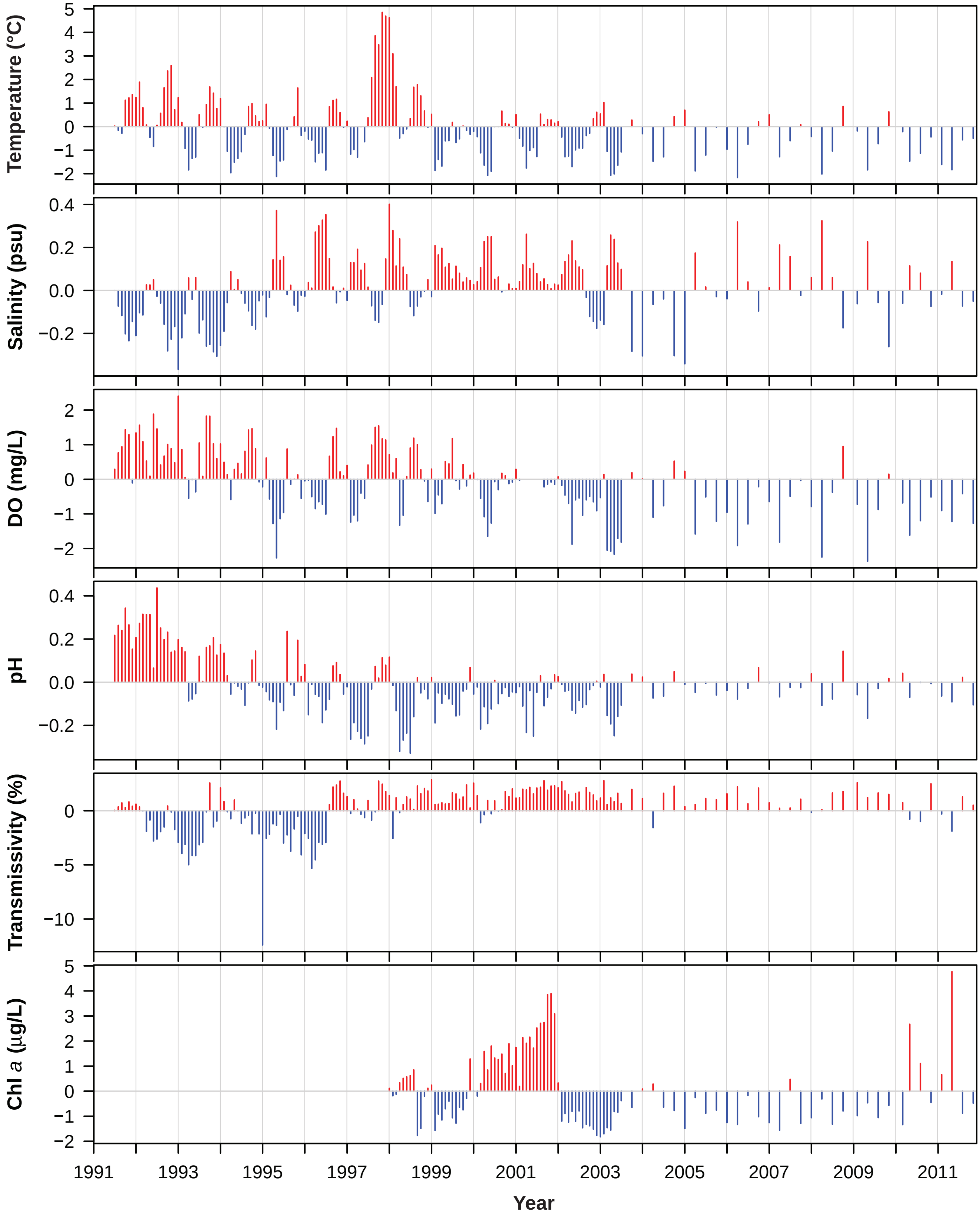

Figure 2.10

Time series of temperature, salinity, dissolved oxygen (DO), pH, transmissivity, and chlorophyll *a* fluorescence (chl *a*) anomalies between 1991 and 2011. Anomalies are calculated by subtracting the mean of all years (1991–2011) combined from monthly or quarterly means of each year; data were limited to all stations located along the 100-m contour, all depths combined.

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